Frequency correction in a mobile radio receiver
using an analogue and a digital control loop

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REFERENCE TO RELATED APPLICATIONS
This application claims the benefit of the priority
date of German application DE 103 14 149.9, filed on
March 28, 2003, the contents of which are herein
10   incorporated by reference in their entirety.

FIELD OF THE INVENTION
The present invention relates to a system and a method
15   for frequency correction in a reception apparatus in
accordance with the independent patent claims. The
invention refers particularly to the frequency
correction in a reception apparatus in a mobile station
in a mobile communication system.
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BACKGROUND OF THE INVENTION
In transmitter/receiver circuits, local oscillators are
used to produce a reference frequency. In receiver
25   circuits, this reference frequency can be supplied to a
mixer stage in which the received signal is mixed
directly or via an intermediate frequency from the
carrier frequency to baseband. Any discrepancy between
the carrier frequency for the received signal and the
30   receiver's reference frequency supplied to the mixer
results in transmission errors in the receiver. Such a
discrepancy can be brought about on account of
production tolerances, temperature and supply voltage
fluctuations in the transmitter and/or receiver and
35   resultant fluctuations in the carrier frequency and/or
reference frequency or by the Doppler effect as a

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result of a relative movement between base station and mobile station.

To counteract transmission errors caused by frequency
5   offset, the transmitter/receiver circuits use, by way of example, expensive, high-quality oscillators which produce a very stable, i.e. fluctuation-free and precise, reference frequency. It is likewise possible to use voltage-fluctuation and temperature-compensated
10 oscillators to reduce the reference frequency's dependency on voltage fluctuations and temperature. In addition, "automatic frequency correction control loops" (AFC loops) are frequently used for precisely setting the local reference frequency. In an AFC
15 control loop, the frequency offset is estimated and the estimate is used to produce a control voltage that is supplied to a voltage-controlled oscillator. The latter's output frequency is used as the input frequency for a PLL control loop. Upstream of the
20 voltage-controlled oscillator, a low-pass filter is used for low-pass filtering of the estimate signal converted into the control voltage. To estimate the frequency offset, a pilot signal having a known content is used in the receiver, for example. If the data rate
25 of the known signal is significantly higher than the possible rate of change of this frequency offset, then it makes sense for the latter not to be corrected until after the estimate has been low-pass filtered. This is frequently indispensable, both in order to improve the
30 quality of the estimates (smaller variance) and in order to prevent unwanted creation of dynamics in the control process, such as oscillation. The low-pass filtering is a crucial drawback for rapid or even abrupt frequency changes.
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Such an abrupt change in the apparent frequency of the transmitter occurs, for example in the 3GPP/UMTS/FDD

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mobile radio system, if the mobile station's reception
is changed over from one base station to another base
station for particular periods of time. In the
"interfrequency compressed mode" operating situation,

5   the original base station's reception is interrupted
and is switched to another base station with another
carrier frequency for measurement purposes. The
switching time provided in the UMTS standard is
extremely short in this case.

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Although the UMTS standard places an extremely high
demand on the base station's carrier frequency
precision, apparent discrepancies of several kHz among
the base stations may arise, for example on account of

15   Doppler effects. Additional discrepancies may arise on
account of switching behaviour and switching delay, as
a result of needing to changeover to a different
carrier frequency in the receiver. Discrepancies are
also possible if the frequency produced in the

20   oscillator or in the downstream PLL control loop for
deriving the pattern frequencies differs from the one
that is set, and the difference is dependent on the
frequency that is set. An example of such a discrepancy
would be an unknown nonlinearity in the oscillator's

25   drive characteristic.

A further scenario for wanted rapid changes in the
carrier frequency with exact timing is the initial
acquisition after turning on the mobile radio. It must

30   be assumed that the oscillator's frequency offset is
next to the actual carrier frequency to such an extent
that no further signal can be received or found. In
this case, a signal search on a plurality of slightly
offset frequencies is desirable. In this context, the

35   changeover operation between the individual frequencies
should take place as quickly and exactly as possible.

Both are impaired by a low-pass filter in the control loop.

Current solutions involve no direct fast correction of
5   the centre frequency in combination with driving the
oscillator. By way of example, for the fast change
between the base stations in the aforementioned
"interfrequency compressed mode" the AFC control
algorithm for the oscillator is stopped in the
10   measurement gap for the second base station, and the
last value in the control chain is maintained without
any subsequent correction at another point. As soon as
reception is switched back to the original base station
again, the control algorithm is continued at the old
15   point. In this case, losses of reception quality in the
measurement gap are therefore accepted.

Another option is simply to allow the AFC control loop
to continue. If the control loop's reaction is fast
20   enough to react within the gap, impairment of the
reception quality in the transitional ranges is
accepted. This is shown in Figure 1.

Changing over the search frequency for the initial
25   acquisition likewise accepts a longer reaction time for
the normal control loop.

SUMMARY OF THE INVENTION
It is thus an object of the present invention to
30   specify a system and a method for frequency correction
in a reception apparatus which avoid any impairment of
the reception quality even in the event of
interruptions in the normal transmission/reception
operating state, particularly when changing over a
35   mobile station to a base station operating at a
different carrier frequency.

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This object is achieved by the features of the independent patent claims. Advantageous developments and refinements are specified in the subclaims.

5   A fundamental concept of the invention is to provide a system for frequency correction in a reception apparatus that has two independently activatable control devices which can be used to detect and correct a frequency discrepancy, the detection being able to be

10   performed by a device which is used by the two control devices jointly. The system has a detection device for detecting a frequency discrepancy, and a first control device for appropriate correction of the frequency supplied to a mixer stage on the basis of the detected

15   frequency discrepancies. The system also has a second control device for subsequent computerized correction using a suitable algorithm.

       Provision can be made for the second control device to

20   have joint use of the means for detecting the frequency discrepancy that are provided in the first control device.

       The suitable algorithm used in the second control loop

25   may be the "CORDIC" algorithm, for example.

       The first control device can be regarded as an analogue frequency controller that involves active intervention in the received signal's processing process and

30   correction of the mixing frequency used to mix the received radio-frequency signal to baseband on the basis of a detected frequency discrepancy. By contrast, the second control device can be regarded as a digital frequency controller that involves taking a detected

35   frequency discrepancy as a basis for merely passive subsequent, for example CORDIC based, computerized correction of the frequency discrepancy. Frequency

correction using the CORDIC algorithm is described in German laid-open specification DE 199 48 899 A1, for example, which is incorporated by reference herein its entirety in the disclosure content of the present
5   application.

A suitable algorithm that may be used for the second control device instead of the CORDIC algorithm is a different algorithm that likewise involves compensating
10   for the frequency discrepancy by means of appropriate counter rotation of the complex received signal.

The inventive system provides the option of activating one or the other of the two frequency control devices
15   or else both frequency control devices in combination on the basis of the situation and mode. In particular, the system may be designed such that only one of the two control devices is active at a time. By way of example, the first control device may be active in the
20   reception apparatus' normal mode, while the second control device is active during predetermined operating states. If the system is used within a mobile station in a mobile communication system, the first control device can be activated during the reception mode with
25   one base station, and the second control device can be activated while the transmission/reception mode is being changed over to another base station.

In line with one embodiment of the inventive system,
30   the first control device can have a PLL control loop that contains a first voltage-controlled oscillator (VCO) whose output frequency is supplied to the mixer stage. In particular, the first control device may in this case have a second voltage-controlled oscillator
35   (VCO), particularly a crystal oscillator, to which a control signal produced on the basis of the detection of the frequency discrepancy is supplied and whose

output frequency is the input frequency for the PLL
control loop. Upstream of the second voltage-controlled
oscillator, a low-pass filter may be used, in
particular.

In line with one embodiment of the inventive system,
the first control loop may have means for detecting the
frequency discrepancy which are part of a RAKE receiver
and which produce a frequency discrepancy signal at
their output. The first control device may also have
means for producing a control voltage to which the
frequency discrepancy signal is supplied and which, for
their part, supply the control voltage to the second
voltage-controlled oscillator.

In line with another embodiment of the inventive
system, the second control loop may have a CORDIC
computation unit that is contained in the reception
path and can be activated and controlled by a control
signal. The first control device may be deactivated at
the same time as the control signal is output and
provided.

The invention also relates to a method for frequency
correction in a reception apparatus, in which, in a
first operating state, a frequency discrepancy in
received signals is detected and a corrected frequency
is supplied to a mixer stage, and, in a second
operating state, a frequency discrepancy in received
signals is detected and subsequent computerized
frequency correction is performed on the basis of a
suitable algorithm, such as the CORDIC algorithm.

The inventive method may be carried out in a mobile
station in a mobile communication system, where the
first operating state is represented by the normal
transmission/reception mode with one base station, and

the second operating state is a state in which the
transmission/reception mode is changed over to another
base station. In this case, the first operating state
may involve the detection of the frequency discrepancy

5   being taken as a basis for producing a frequency
discrepancy signal, and a control voltage derived from
the frequency discrepancy signal may be supplied to a
voltage-controlled oscillator (VCO). The output
frequency from the voltage-controlled oscillator is

10   supplied to a PLL control loop, and the latter's output
frequency is in turn supplied to the mixer stage.
During the second operating state, the output frequency
that is output by the voltage-controlled oscillator at
the time of the changeover from the first to the second

15   operating state can be maintained. The voltage-
controlled oscillator is "frozen" to a certain extent.
Hence, although the output frequency which is output by
it and supplied to the PLL control loop and the
frequency which the PLL control loop supplies to the

20   mixer stage are not correct, this is unimportant, since
the frequency correction is performed during the second
operating state by the second, for example, CORDIC-
based, control device.

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              BRIEF DESCRIPTION OF THE DRAWINGS
The invention is explained in more detail below with
reference to graphs and an embodiment, where

30   Figure 1   shows the frequency setting and the signal
                quality in a conventional frequency-corrected
                system against time and the operating modes;

     Figure 2   shows the frequency setting and the signal
35   quality in an inventive system for frequency
                correction against time and the operating
                modes; and

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Figure 3   shows an embodiment of an inventive system
           for frequency correction.

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          DETAILED DESCRIPTION OF THE INVENTION
Figure 3 shows a system 100 for frequency correction
within a reception apparatus in a mobile communication
system. This illustration, in one example, shows a
10   received signal processing chip in the bottom right-
hand portion and external components in a top left-hand
portion.   The system 100 comprises both components on
the received signal processing chip and external
components.   However, it should be understood that the
15   present invention extends to integrated frequency
corrections systems and are contemplated as falling
within the scope of the present invention.   The dashed
lines identify the control loops RS1 and RS2. The
control loop RS1 relates to the active, analogue
20   frequency correction that is used to change the
frequency supplied to the mixer stage. The control loop
RS2 relates to a digital frequency correction on the
basis of the CORDIC algorithm.

25   A received signal is supplied to the RF reception chip
19 by the duplexer 8. The RF reception chip contains a
mixer/amplifier/filter assembly 18 in which the
received signal is mixed to baseband, amplified and
filtered in a mixer stage. The mixer stage in the
30   assembly 18 is supplied with the frequency as the
output frequency from a voltage-controlled oscillator
(VCO) 16 associated with a PLL control loop 15. The PLL
control loop 15 is supplied with an input frequency
f_{BASIS} by a voltage-controlled oscillator (VCO) 14.

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The received signal mixed to baseband is supplied to an
analogue/digital converter (ADC) 20 by the assembly 18

and is then input into a combined filter/sampling-rate
converter assembly 21. This is followed in the
reception path by a CORDIC computation unit 22, which
can be activated by applying a control signal f_{cordic} to
5   it and is bridged by the reception path in the inactive
state. Next, the signals are filtered in a terminating
reception filter, for example an RRC (root raised
cosine) filter unit 23 used as a pulse shaper, and are
input into a RAKE receiver 30 in this state.
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Within the RAKE receiver 30, there is an AFC
preprocessing stage 31, designed in hardware, which is
used to detect a frequency discrepancy in the received
signal. This can be done, by way of example, by virtue
15   of a phase difference in signals received at different
times being detected, and this phase difference being
subsequently used as a control variable, as described
in German laid-open specification DE 101 22 692 A1, for
example, which is incorporated by reference herein in
20   the disclosure content of the present application.

The AFC preprocessing unit 31 generates a frequency
discrepancy signal and supplies it to an AFC control
unit 10 designed in firmware. The AFC control unit
25   delivers a control signal to the oscillator control
unit 11 designed in software, which outputs a control
voltage and supplies it to the crystal oscillator 14
via an oscillator interface 12 and a low-pass
filter 13.
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The AFC frequency correction that is known per se
becomes noticeable in the first control loop RS1. In
the AFC preprocessing unit 31, a frequency discrepancy
is established and the control units 10 and 11 are used
35   to deliver a control voltage to the crystal oscillator
14, which in turn uses a changed output frequency f_{BASIS}
to drive the PLL control loop 15, so that the

oscillator 16 drives the mixer stage at a corrected frequency. In the mixer stage, the received signal is mixed to baseband directly or via an intermediate frequency.

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In the second control loop RS2, a digital frequency correction is performed on the basis of the CORDIC (coordinate rotation digital computer) algorithm in the CORDIC computation unit 22. The frequency discrepancy

10   signal produced by the AFC preprocessing unit 31 is transmitted to the CORDIC computation unit 22 by the control unit 10 as a control signal f_{CORDIC}. The CORDIC computation unit 22 is designed in hardware and has, by way of example, a series circuit comprising a number of

15   microrotation blocks in which a vector having an in-phase component and a quadrature component is respectively rotated through a prescribed angle, as described in the aforementioned German laid-open specification DE 199 48 899 A1, for example. It is

20   therefore clear that CORDIC-based control is based on the start of the reception path being split into an in-phase branch and a quadrature branch.

The inventive system is used in a 3GPP-UMTS-FDD-mobile

25   radio system, for example. In this example, the mobile station changes over to a different base station (BTS) from time to time for measurement purposes. While the mobile station is in the second operating mode, the frequency correction is performed only by the second

30   control loop RS2. The AFC preprocessing unit 31 continues to detect any frequency discrepancies that there may still be and delivers corresponding frequency discrepancy signals to the AFC control unit 10, the frequency discrepancy signals being used by the CORDIC

35   computation unit.

The invention thus achieves the object by means of combined control of the centre frequency. First, the standard control is maintained by the AFC frequency correction using the oscillator 14. The AFC frequency

5   correction corrects the frequency offset under normal conditions and, in the control loop, contains the aforementioned stabilization through low-pass filtering using the low-pass filter 13. Secondly, additional control is provided in the digital front end by driving

10   the CORDIC computation unit 22 formed in hardware. In this way, the centre frequency of the received signal can be shifted by subsequent computational correction without any significant delay and irrespective of the driving of the oscillator 14.

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For the example of the aforementioned "interfrequency compressed mode", the control of the oscillator 14 can be frozen during the compressed mode gap, so that from then on control is affected only by means of the

20   digital control loop RS2. The immediately available shift in the centre frequency may be based simply on measurements from preceding compressed mode gaps. When switching back to the original base station, the digital control loop RS2 is deactivated again and the

25   old centre frequency is immediately available. Figure 2 indicates how the signal quality can be kept constant through improved frequency correction on the basis of the inventive method.

30   Provision may likewise be made for the two control loops RS1 and RS2 to operate simultaneously so as to achieve more exact frequency correction in particular situations. However, it is preferable for only the second control loop RS2 to be activated, particularly

35   in the case of frequency corrections that are required at short notice, so as not to impair the oscillator control loop RS1.